TIE SUPPORT SYSTEM FOR INSULATED MASONRY VENEER CONSTRUCTION

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

TIE SUPPORT SYSTEM FOR MASONRY VENEER CONSTRUCTION

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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EXECUTIVE SUMMARY

This report describes the development and testing of a new masonry tie support which facilitates the construction of masonry veneer walls with insulation in the cavity. This tie support is designed to transfer all external loads acting on the masonry veneer to the back-up wall system.

Information on the development of the masonry tie support is followed by the findings of an extensive testing program of individual tie supports, small wall assemblies and full scale wall systems. The results obtained indicate that the tie support system can carry all applied service loads with a safety factor larger than five.

Incorporation of the tie supports in the construction of masonry veneer walls with insulation in the cavity will provide for reducing the cavity to the air space only whereas if the tie is attached directly to the metal stud, for design purposes the cavity width is that of the air space plus the insulation thickness.

Since the insulation is applied by a different subtrade, prior to the installation of the brick wall, the tie support will also facilitate the actual construction by allowing the fastening of the masonry veneer wall to the back-up system after the insulation is positioned.

The cost of the wall system will be reduced because structural corrugated strip ties can be used instead of the heavy duty rod, or other types of ties required to safely transfer the loads. The two systems now available, which are also briefly discussed here, cost from $1.50 to $2.35 per unit whereas the device developed will provide the same functions at a total cost of $.85 per tie.

CHAPTER I. Introduction

The increased demand for higher levels of insulation in wall assemblies is most commonly met by replacing the exterior sheathing with suitable insulation, or by placing insulation on top of the exterior sheathing. This method has become very popular with wall systems incorporating metal or wood studs in both new and retrofit construction.

These wall systems are often finished with brick cladding applied as a veneer wall with a minimum air space of 25 mm between the insulation and the brick veneer wall. The veneer wall is designed to transfer the wind induced loads acting on it to the back-up wall by means of masonry ties, which must be securely fastened to the back-up wall system. Because of its low compressive strength, the ties can not be fastened to the insulation. Also, greater insulation thickness increases the distance between the structural back-up wall and the veneer. Accordingly much heavier ties must be used because they must be structurally designed for an unsupported length consisting of the air space plus the thickness of the insulation.

Finally, securing the ties directly to the back-up wall after the insulation is placed presents a difficult and messy construction sequence. To properly connect conventional ties to the back-up wall system the insulation must be interrupted at the location of every tie, which will affect the insulation value of the wall.

This report contains the findings of a theoretical and experimental evaluation of a device referred to here as a tie support system designed to be applied on top of exterior sheathing-type insulation, which is capable of transferring the wind and other loads to the back-up wall system with minimum interruption of the insulation.

Also included in the report is a brief evaluation of existing masonry tie systems which are being used to transfer wind loads from veneer walls to a metal stud back-up system.

The experimental part of this study contains the findings of tests carried out on individual support devices and wall assemblies.

The assemblies tested consisted of small wall sections built in accordance with standard construction procedures with the tie support system applied on top of the insulation. Also reported are the results obtained from the testing of four full scale walls. The effect of the type and size of insulation, the type and thickness of ties and type of back-up wall system were evaluated.

CHAPTER II. Existing Tie Support Systems

There are a number of masonry tie support devices being used which are specifically designed to provide support to brick veneer ties in wall systems using exterior sheathing insulation on metal studs. Two typical devices were chosen for review here. Figures 1, 2 and 3 on pages 4 and 5 show these devices.

The screws used to secure the device shown in Figure 1 are loaded in shear and are located on the web of the stud and therefore corrosion of the thread is not expected to cause a catastrophic failure. This makes this system desirable for areas where corrosion levels are expected to be high. The second device, shown in Figure 3, locks on the stud flange and is not dependent on screws for connection or support.

Both devices are suitable for use in conjunction with rod-type ties, however they must be installed prior to the installation of the insulation which can interfere with the construction sequence. When the back-up wall system is not masonry, the mason contractor is not responsible for installing the insulation. In that case he must install ties and accessories to a system completely hidden by insulation. Also, because of their size and metal contact area, their use will reduce the thermal efficiency of the wall system.

In summary, the existing masonry tie supports are not popular with the masonry industry, mainly because of their cost and the awkward construction sequence they necessitate.

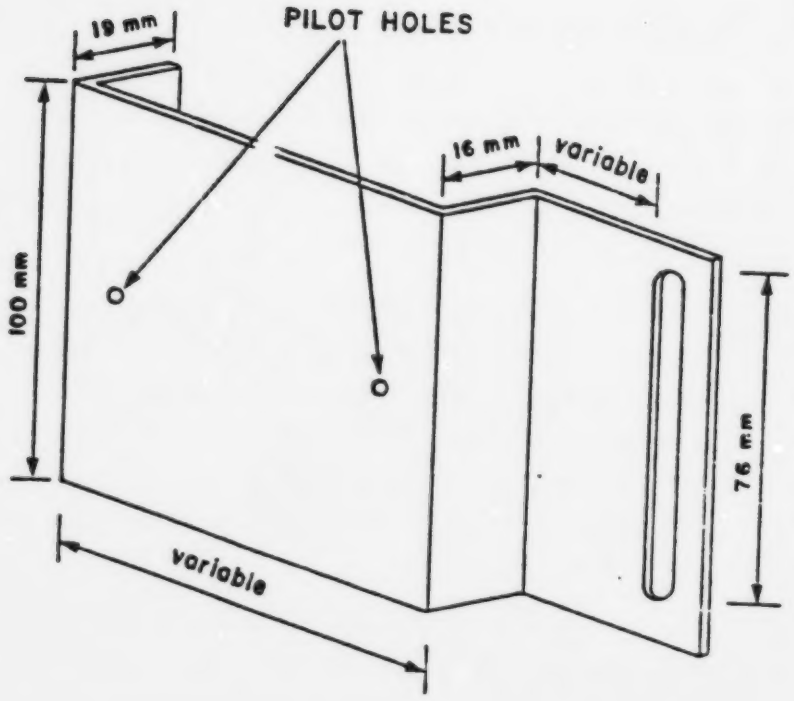


Figure 1. Commercially Available Device for Tie Support

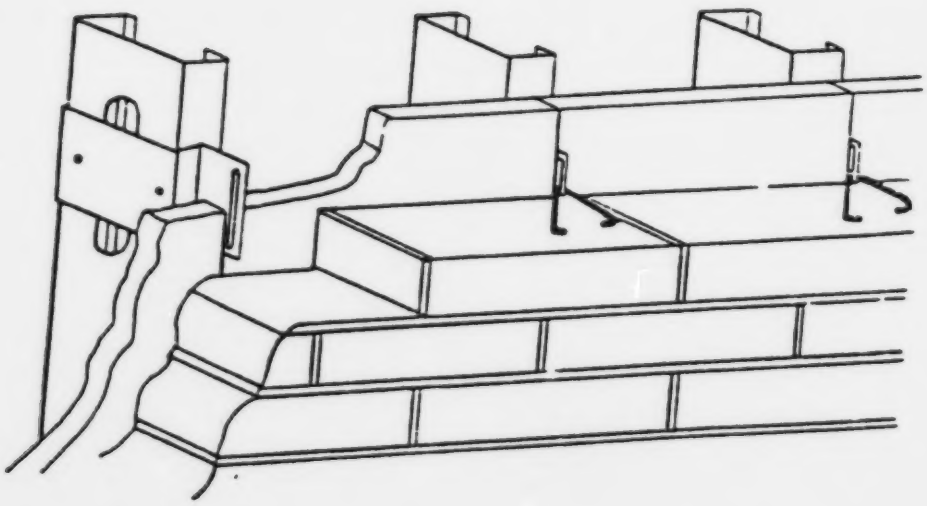


Figure 2. Commercially Available Adjustable Tie Support System

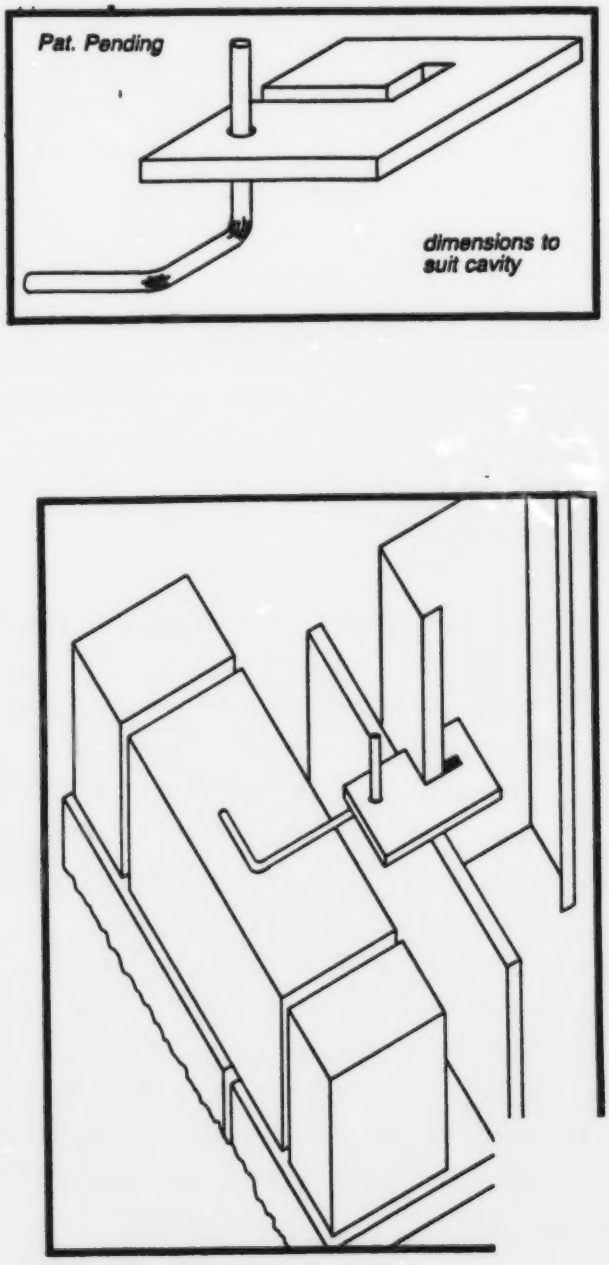


Figure 3. Flange Locking Adjustable Device for Tie Support

CHAPTER III. Development of the Masonry Veneer Tie Support System

The design criteria for a new masonry tie support system arose primarily from the experience with normal systems described in Chapter 2. The main criteria for an improved system are that the new tie support:

i) be appropriate for use with exterior sheath-type insulation system;
ii) respect traditional construction sequencing and trade responsibilities (i.e. that the tie support be placeable by masons after the insulation has been applied;
iii) accomodate various thicknesses of insulation;
iv) provide adequate stability, strength and corrosive resistance; and
v) be cost effective.

The new tie support is shown schematically in Figure 4, on page 7 and in Photo 1, on page 8. It is manufactured from 16 gauge hot dipped galvanized sheet metal punched as shown in Figure 4 and folded 90° along the lines A-A and B-B. Bending resistance is provided by a 5 mm leg forming a channel on both sides of the seat portion of the device. Photo 1 shows such devices suitable for use in conjunction with 25 mm, 38 mm and 50 mm insulation. When placed on top of the insulation and pushed in, the triangular legs of the device come in contact with the metal stud or other framing materials to provide for compressive loads. Lateral stability is provided by restraint from the drywall, rigid or semi-rigid insulation into which the triangular legs of the tie support are forced. The three holes in the device facilitate the fastening of different types of ties such as corrugated strip ties or adjustable ties. The tie support is stable when fastened through any one of the three holes.

To accommodate various thicknesses of insulation the depth of the devices shown as H in Figure 4 varies from 25 mm to 75 mm (75 mm being the maximum thickness of sheet insulation presently used in this type of application).

Figures 5 to 7, on pages 10 through 12 show the application of the new support in conjunction with various tie systems. Once assembled, the screws will take tensile loads and compression loads are transferred to the back-up system by the four contact points of the tie support device.

Photo 1. Tie Support System

MATERIAL : 16 GAUGE GALVANIZED METAL

ALL HOLES TO BE 4.76 mm DIAMETER

FOLD 90° ALONG LINES 'A' AND 'B'.

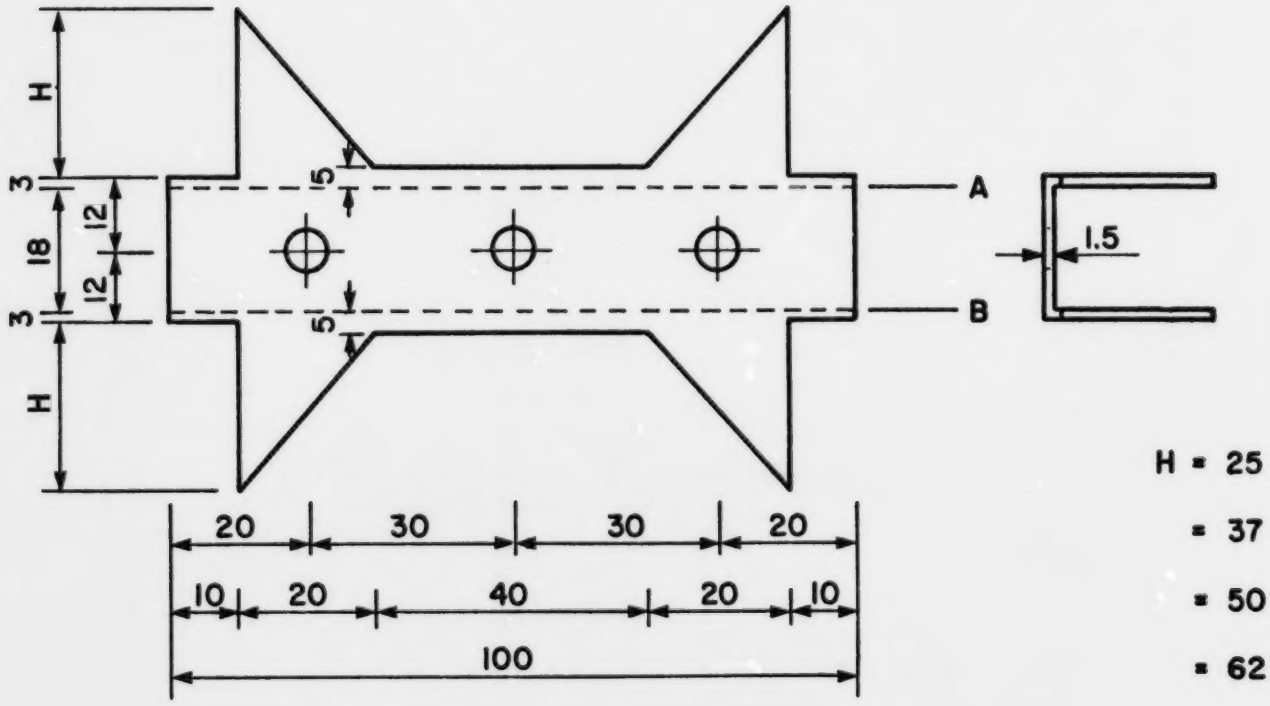


Figure 4. Manufacturing Details of Tie Support System

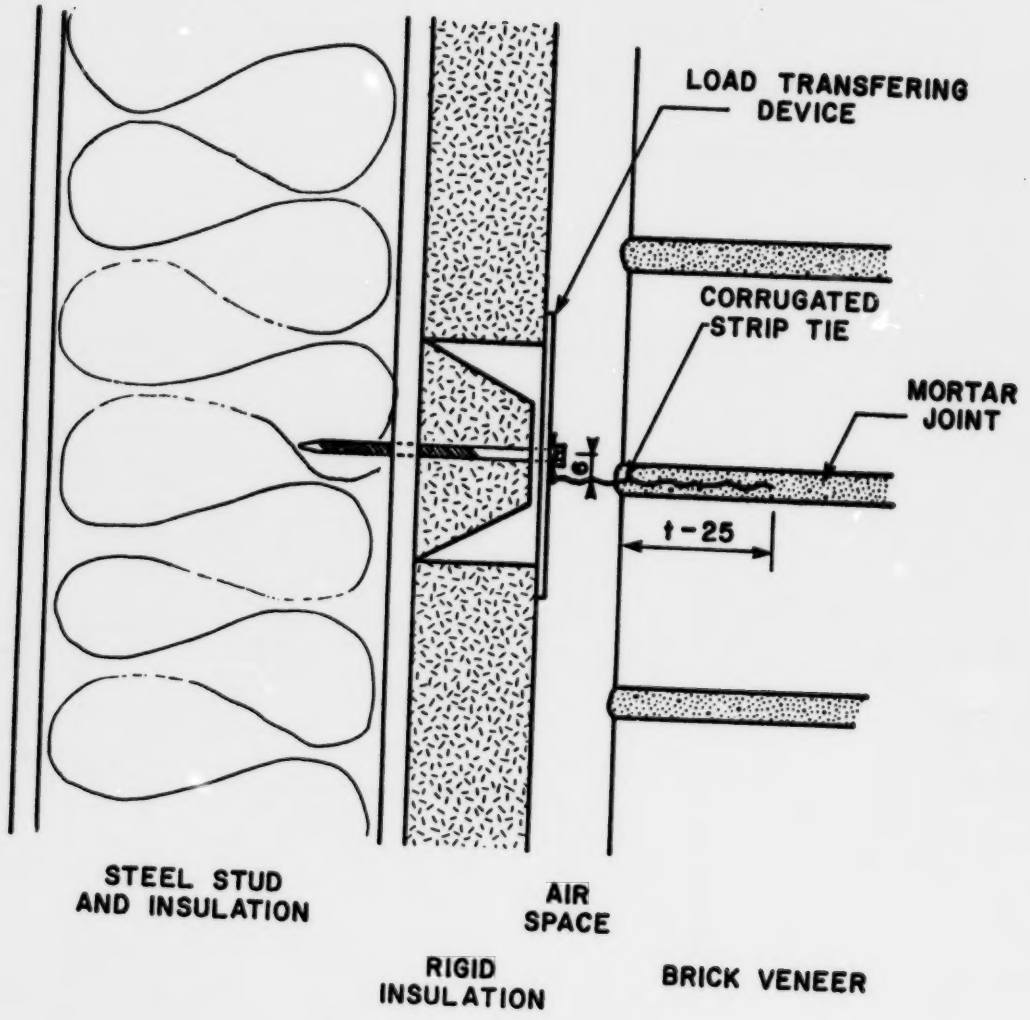


Figure 5. Device Installation Using Corrugated Strip Tie

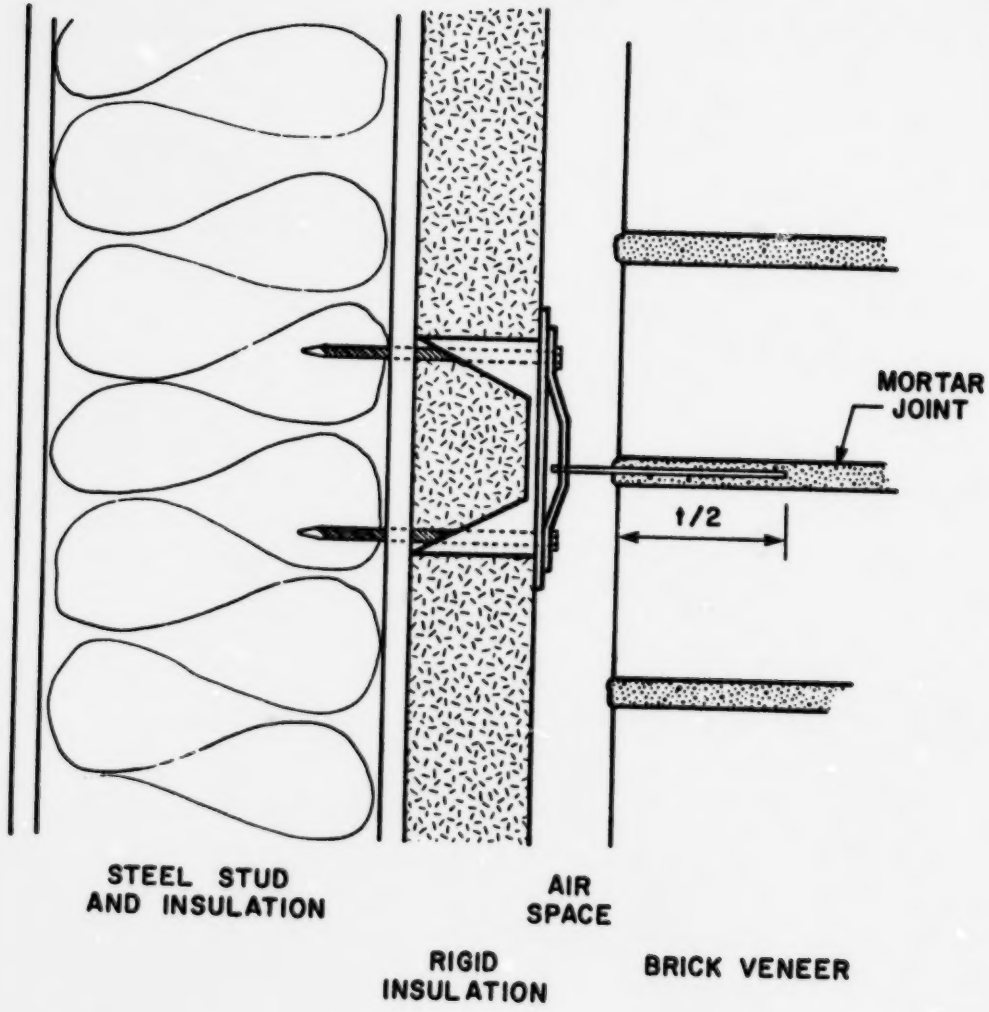


Figure 6. Installation of Device with Adjustable Veneer Tie

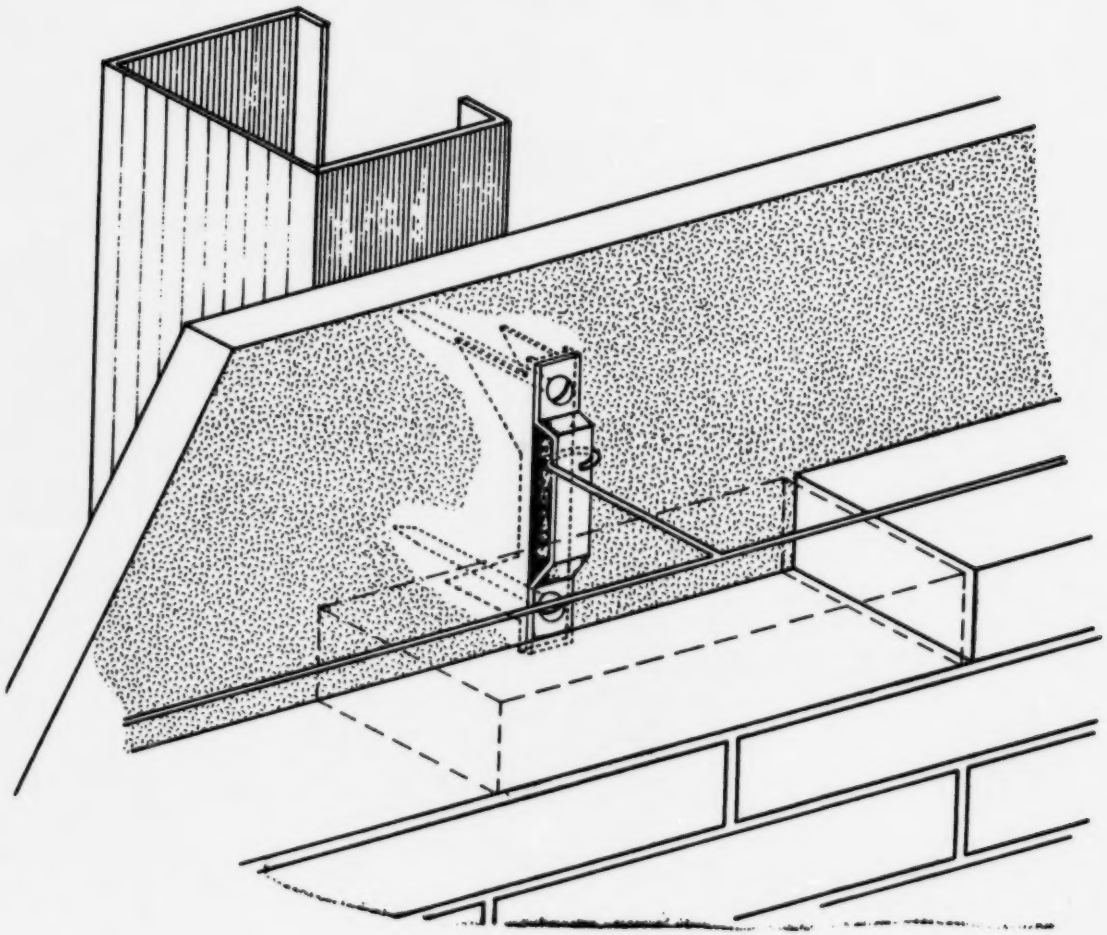


Figure 7. Device with Adjustable Continuous Brick Joint Reinforcement

CHAPTER IV. Theoretical Evaluation

The most critical loading condition occurs when a concentrated load is applied at the midspan of the masonry tie support device. The device was analyzed using a computer frame analysis program with a concentrated load P applied at mid-span as shown in Figure 8 on page 15.

In order to facilitate the analysis, the device was modelled as shown in Figure 9 on page 15. The physical properties along the legs of the device were taken as the average between the nodal points as shown in Figure 10 on page 16. The legs and the horizontal element of the tie support were divided into 13 elements of which 12 had variable moments of inertia and 1 (#7) had a constant moment of inertia shown in Figure 11 on page 16. Two devices were analyzed, one with height of 25 mm and one with 75 mm in height. The results obtained from the analysis of the device with H = 25 mm are shown in Figure 12, on page 17, and those for H = 75 mm are shown in Figure 13, on page 18. A complete computer analysis output is provided in the Appendix.

The maximum moment occurs (as expected) at the location of the load, 'P', and this moment is of the order of 0.0087P kN-m for the tie support with a height of 75 mm.

Referring to Figure 8 the properties of the section are:

Section Area $A = 42\ mm^2$

Moment of Inerta about the X axis

$$I_{XX} = 65.841\ mm^4$$

Location of neutral axis $\bar{X} = 1.375$ mm from the top.

Maximum Distance from Neutral Axis to the Tension Face

$Y = 5 - 1.375 = 3.625$ mm

For material yield strength, 'σ', of 480 N/mm^2 and using the relation: $\sigma = \frac{MY}{I}$. The maximum load P that can be applied at mid-span can be found as follows.

Since $M = 0.0087\ P$ kN/m (see Figure 10, on page 15)

substituting $\sigma = 480\ N/mm^2$

$Y = 3.625$ mm

$I = 65.841\ mm^4$

and solving for P, we obtain

$$P = \frac{480 \times 65.841}{3.625 \times 0.0087 \times 10^6} = 1.00 \text{ kN or } 224 \text{ lb.}$$

where P is the maximum load the device can theoretically resist.

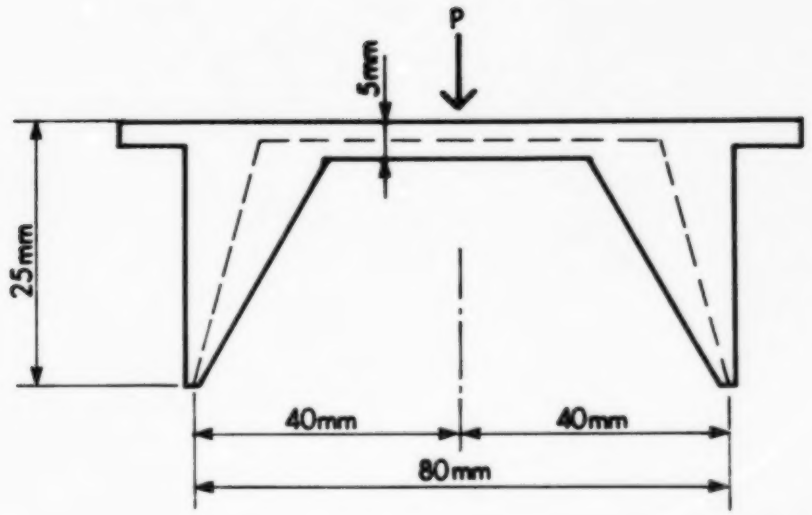


Figure 8. Location of Load

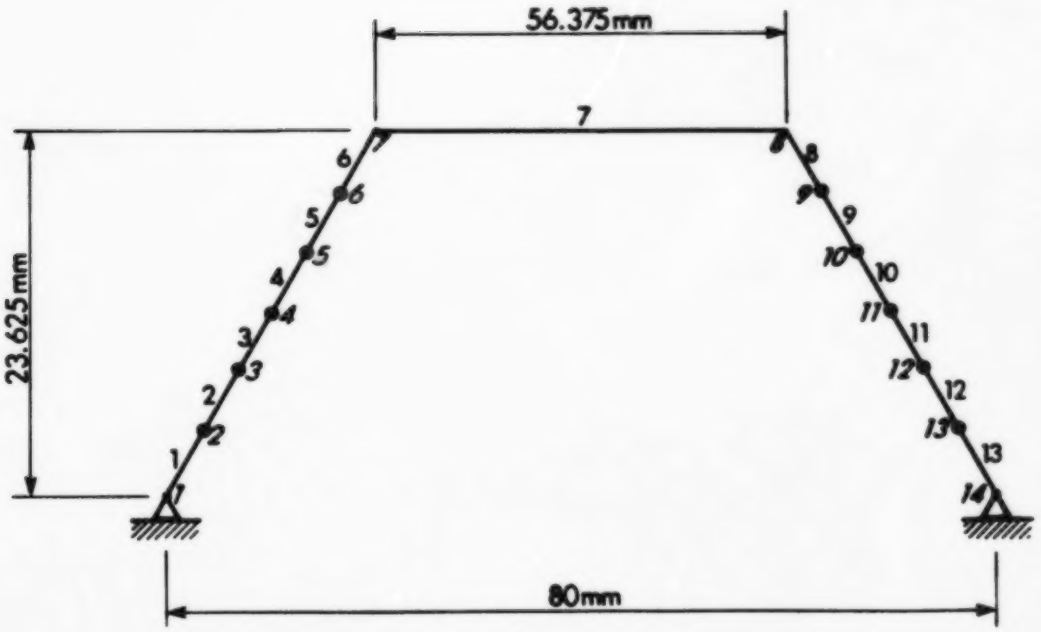


Figure 9. Modelling of Device for Analysis

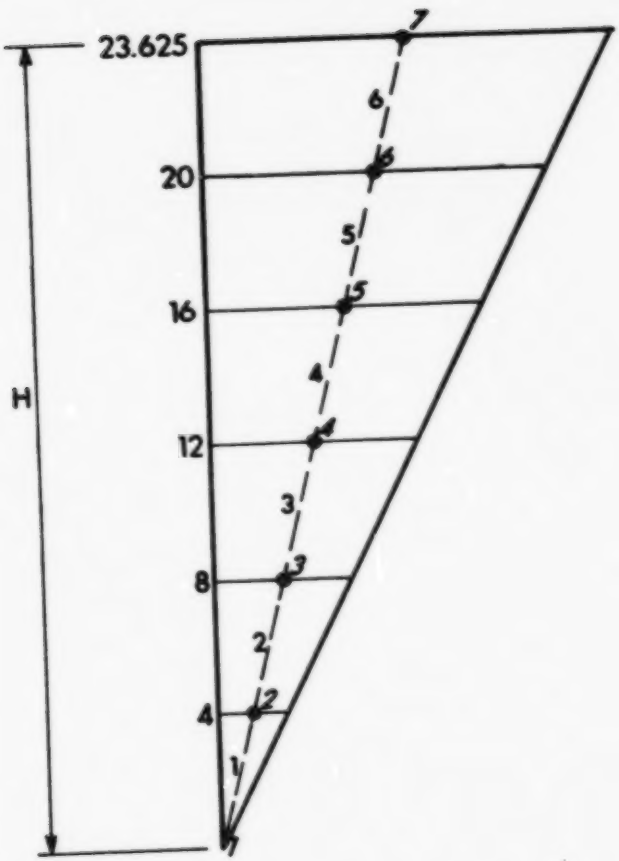


Figure 10. Modelling of Vertical Portion

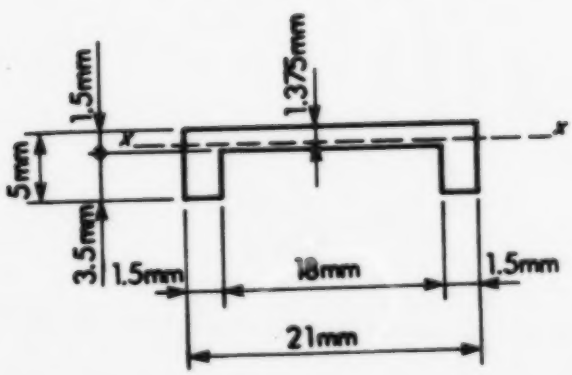


Figure 11. Section through the Horizontal Part of the Device Modelled as Element #7

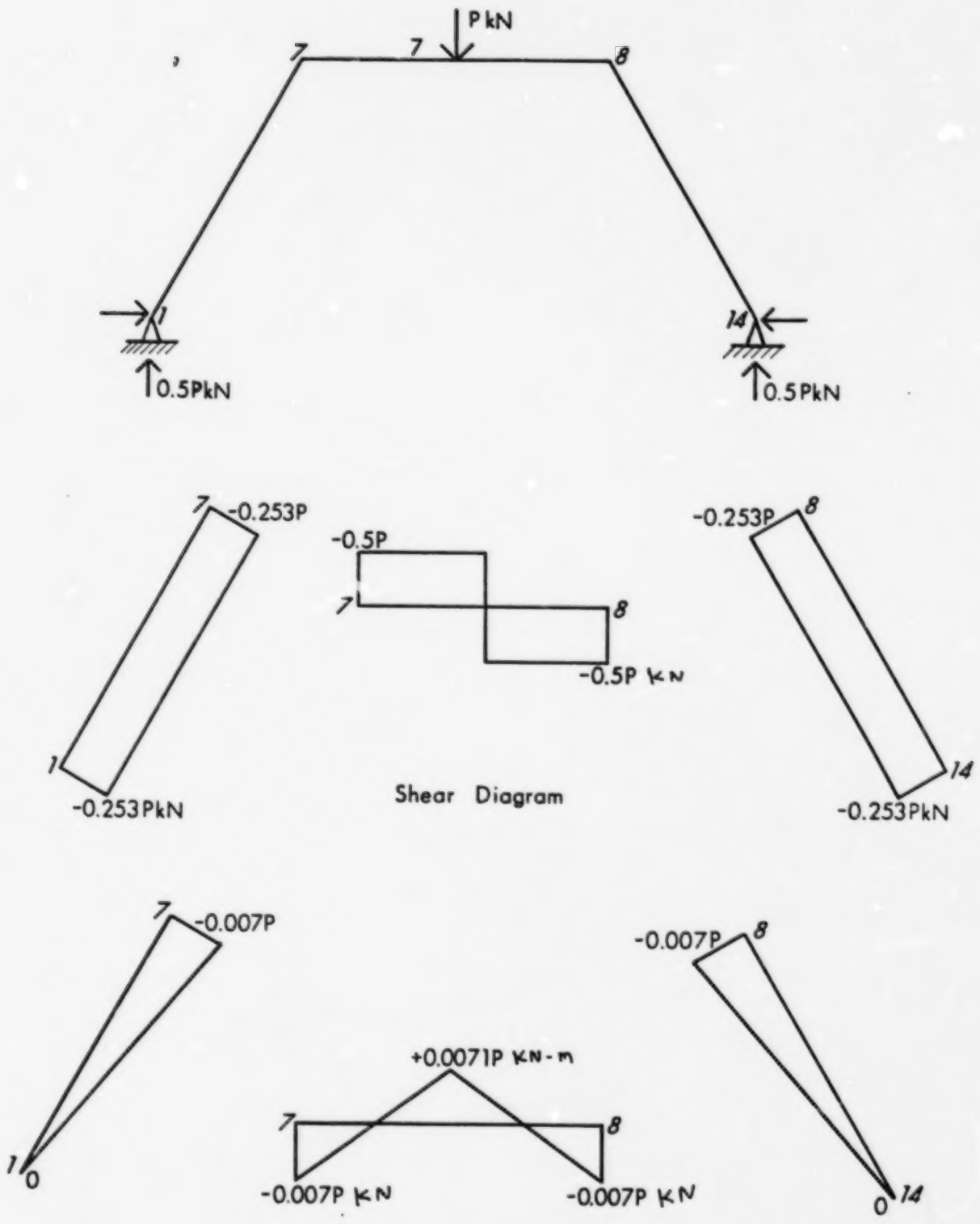


Figure 12. Shear and Moment Diagrams for H = 25 mm

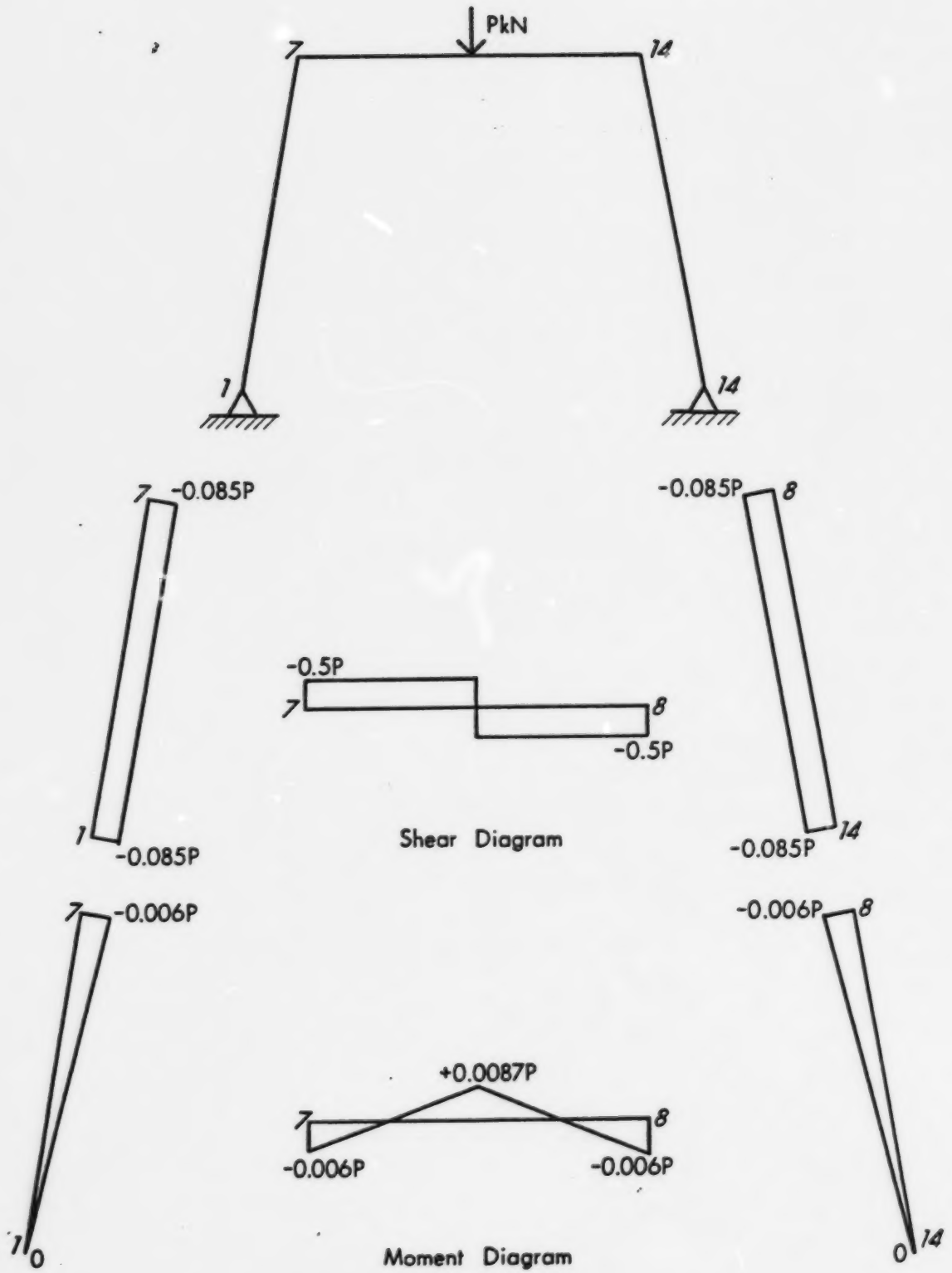


Figure 13. Shear and Moment Diagram for H = 75 mm

CHAPTER V. Experimental Evaluation

A. Introduction

This chapter contains the findings of the experimental program undertaken to evaluate the performance of the tie support devices developed, under conditions similar to those expected in actual construction. The first part relates to tests undertaken to study the failure modes of individual devices tested with a concentrated load applied at mid-span.

The second part relates to tests performed on individual assemblies of tie support devices attached on top of insulation and metal or wood studs and corregated strip masonry ties. This part of the experimental program evaluates the performance of the tie support device and the accessories needed to complete the assembly (screws, corrugated strip ties, insulation, etc.).

The third part evaluates the performance of full scale walls built with the tie support device connecting the masonry ties to the back-up metal stud wall.

B. Individual Testing of the Support Devices

A number of devices, constructed with 16 gauge (1.5 mm) thick metal, were individually tested by applying a concentrated load at mid-span using the apparatus shown in Photo 2, on page 21. The devices were supported by a metal plate in order to simulate support conditions similar to those expected when the device is applied on top of metal studs. During the testing no slippage occurred and the devices failed when the moment capacity was reached at the mid-span. The test results obtained are given on Table 1, on page 20.

Failure modes are shown in Photo 3, on page 22. The average load at failure for the 30 units tested was 0.95 kN, which is very close to the load capacity obtained from the frame analysis in the theoretical part of this study.

Test No.	Maximum Load, kN (lb.)		
	H = 25 mm	H = 37 mm	H = 50 mm
1	0.92 (207)	0.95 (213)	0.96 (215)
2	0.85 (191)	0.97 (218)	1.14 (255)
3	0.90 (202)	0.95 (213)	1.07 (239)
4	0.90 (202)	0.92 (207)	1.04 (234)
5	0.92 (213)	0.85 (191)	1.00 (223)
6	0.95 (213)	0.85 (191)	1.00 (223)
7	0.88 (197)	0.90 (202)	1.00 (223)
8	0.92 (207)	0.97 (218)	1.00 (228)
9	0.83 (186)	0.90 (202)	1.00 (223)
10	0.95 (213)	0.90 (202)	1.00 (228)
Average	0.902 (202)	0.916 (205)	1.021 (220)

Table 1. Individual Tie Support Compression Test Results

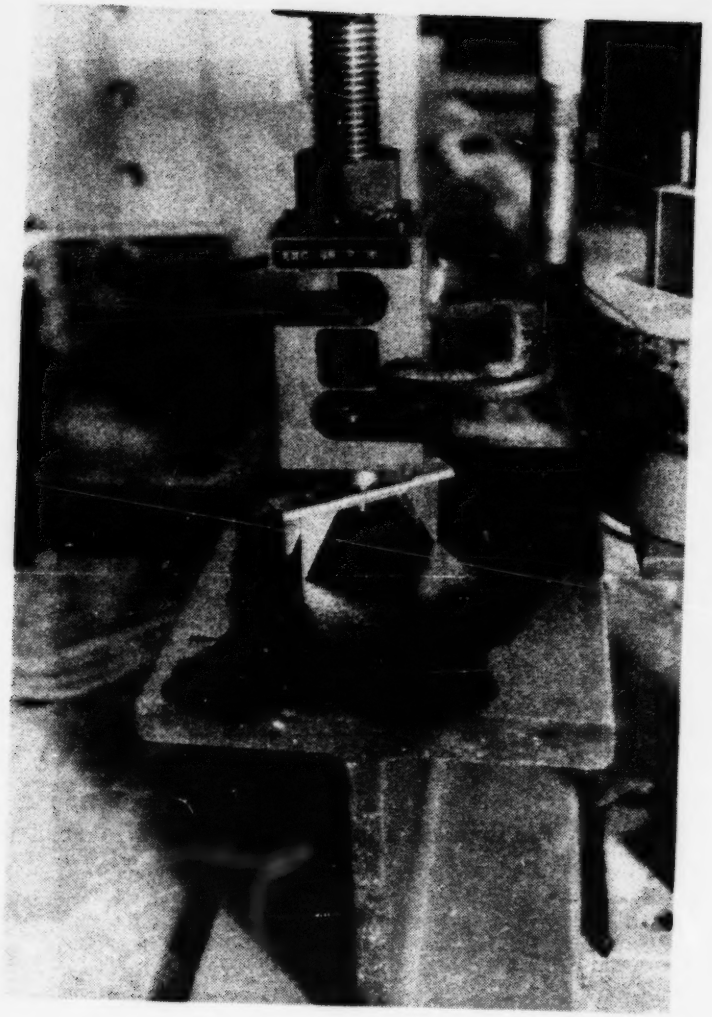


Photo 2. Procedure Used for Testing Individual Devices

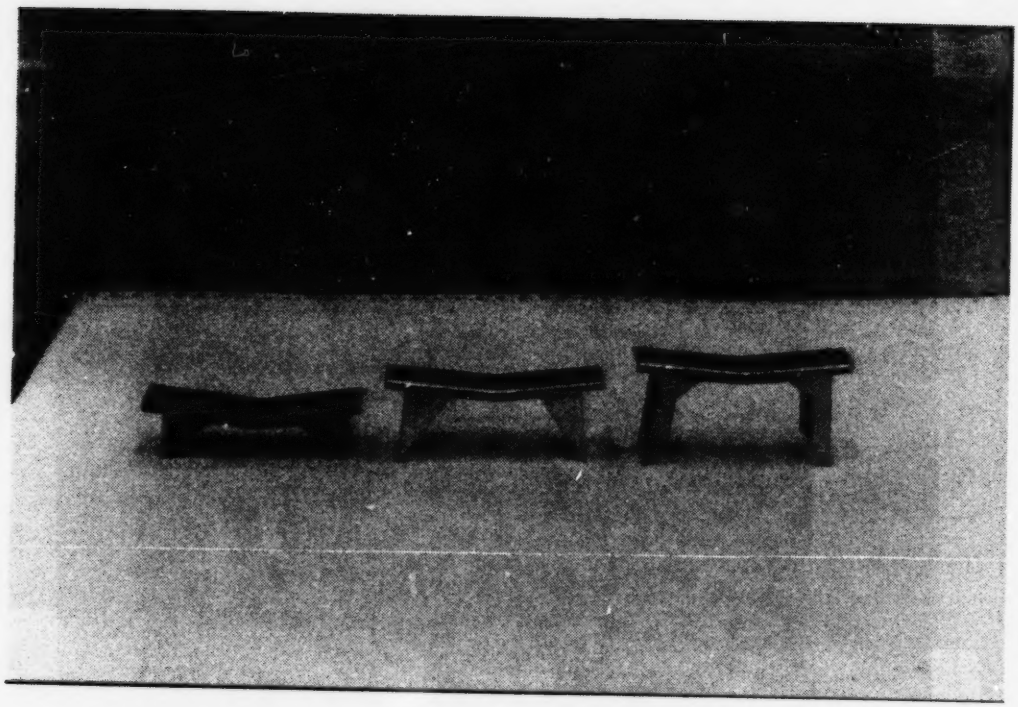


Photo 3. Failure of Individual Devices in Bending

From Table 11 of CSA Standard S304 (1) the maximum area per corrugated tie is 0.24 to 0.32 m^2. Using a typical wind pressure of 1.44 kN/m^2 results in a corrugated tie load of the order of 0.460 N. The maximum calculated load that can be carried by the support is of the order of 0.950 kN. Thus, the maximum design load is only about 50% of the calculated failure load of the device at the maximum allowable tributary area.

C. Performance of Assemblies

C.1 Metal Stud Walls

The tie support device was tested in conjunction with sheathing insulation applied on the exterior of metal studs. Figure 14, on page 24 shows the assembly and apparatus used in the experimental part of this study.

The dimensions of the wall panel used to test the devices were 1.2 m x 1.2 m, with 18 gauge metal studs spaced at 400 mm on centre. Photo 4, on page 25 shows the test set up. Variables tested in this part of the experimental program were insulation type and corrugated strips thickness. The assemblies were tested for compressive and tensile loads.

Only 22 and 16 gauge corrugated strip ties were tested. Photos 5 and 6, on page 26 and 27 show failures of ties attached on top of devices. The results obtained are given in Tables 2, 3 and 4, on pages 28, 29 and 30, where the failure modes are also identified.

When the system was tested in tension, the screw fastening the device to the metal stud became (as expected) the critical connection.

C.2 Wood Frame Walls

Similar test results were obtained when the tie supports were tested on 38 x 89 wood framed walls with styrofoam and fiberglas insulation. No appreciable compression of the insulation was observed which could be attributed to penetration of the supports of the device into the wood. Results from this part of the study are shown in Table 5, on page 31.

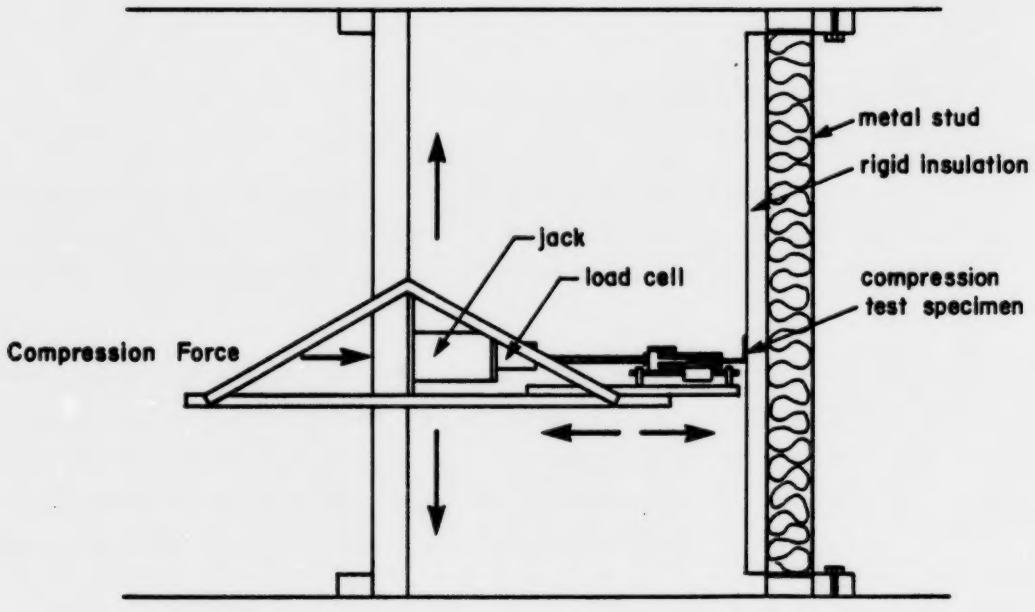


Figure 14. Test Loading Apparatus

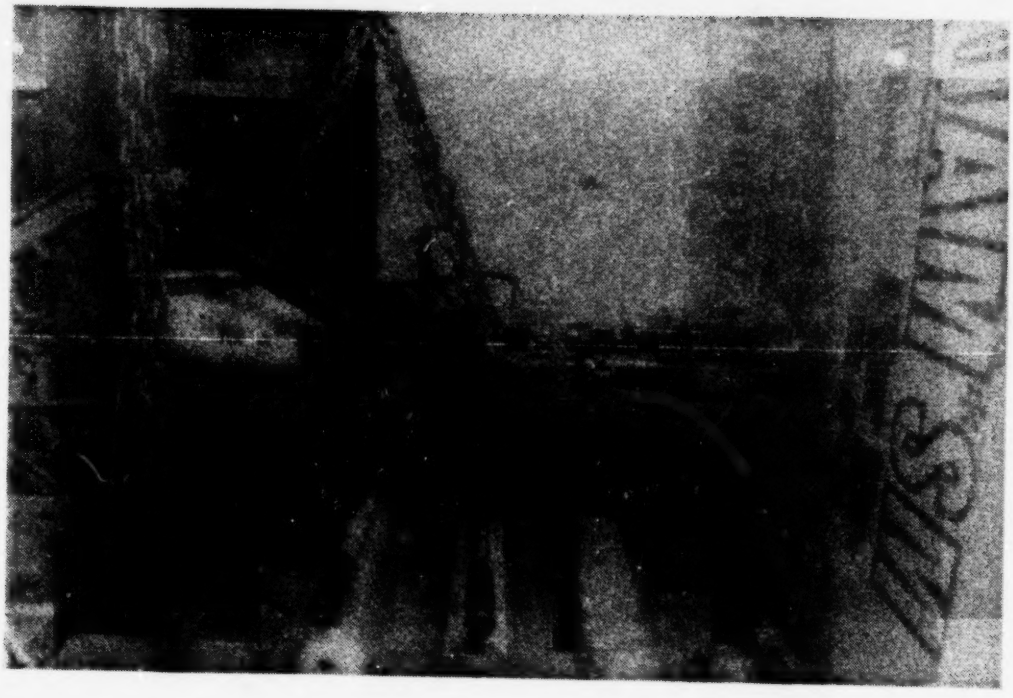


Photo 4. Test Setup

Photo 5. Buckling of 18 Gauge Strip Tie

Photo 6. Failure of 22 Gauge Strip Tie

Table 2. Compression Test Results

22 Gauge Corrugated Strip Tie on 18 Gauge Metal Stud

Specimen No.	1" Insulation		Air Space		Screw Type*	Max Load	Failure Mode
	Rigid	Semi-Rigid	25 mm	50 mm	A	(N)	
1	✓			✓	✓	428	Tie Buckled
2	✓			✓	✓	384	Tie Buckled
3	✓			✓	✓	395	Tie Buckled
4		✓		✓	✓	442	Tie Buckled
5		✓		✓	✓	520	Tie Buckled
6		✓		✓	✓	463	Tie Buckled
7	✓		✓		✓	805	Tie Buckled
8	✓		✓		✓	840	Tie Buckled
9	✓		✓		✓	752	Tie Buckled

* Screw A - Overall length = 51 mm
- Diameter = 4.09 mm
- Diameter at root of thread = 2.92 mm

Screw B - Overall length = 56 mm
- Diameter = 5.38 mm
- Diameter at root of thread = 4.45 mm

Table 3. Compression Test Results

16 Gauge Corrugated Strip Tie on 18 Gauge Metal Stud

Specimen No.	1" Insulation		Air Space		Screw Type*		Max Load	Failure Mode
	Rigid	Semi-Rigid	25 mm	50 mm	A	B	(N)	
11	✓		✓			✓	1557	Device Failed
12	✓		✓			✓	1504	Device Failed
13	✓		✓			✓	1615	Device Failed
14	✓			✓		✓	899	Tie Buckled
15	✓			✓		✓	1001	Tie Buckled
16	✓			✓		✓	943	Tie Buckled
17		✓	✓			✓	1668	Tie and Device Failed
18		✓	✓			✓	1721	Device Failed then Tie Buckle

Table 4. Tension Test Results

22 Gauge Corrugated Strip Tie on 18 Gauge Metal Stud

Specimen No.	1" Insulation		Air Space		Screw Type*		Max Load (N)	Failure Mode
	Rigid	Semi-Rigid	25 mm	50 mm	A	B		
21	✓			✓	✓		1657	Screw Pulled out of the Stud
22	✓			✓	✓		1746	Screw Pulled out of the Stud
23	✓			✓	✓		1612	Screw Pulled out of the Stud
24		✓		✓	✓		2257	Screw Pulled out of the Stud
25		✓		✓	✓		1428	Screw Pulled out of the Stud
26		✓		✓	✓		1779	Screw Pulled out of the Stud

Table 5. Compression Test Results

for Devices Attached on 38 x 89 mm Wood Studs

Test No.	Maximum Load, kN (lb)		
	H = 25 mm	H = 37 mm	H = 50 mm
1	0.91 (202)	0.98 (218)	1.00 (223)
2	0.96 (213)	0.96 (213)	
3	0.96 (213)	0.96 (213)	1.12 (250)
4	0.96 (215)	1.01 (226)	1.24 (276)
5	0.91 (202)	0.96 (213)	1.05 (234)

Load increases were observed for specimens tested on top of styrofoam insulation. It should be pointed out that no complete failure was observed during this testing because of small penetration of the edges of the device into the wood. The behaviour of the support device was changed from that of a frame simply supported to that of a fixed end condition with arching action.

Because the supports penetrate into the wood, rotation at this point is restricted. Then restraint provides for a moment connection.

D. Full Size Wall Tests

In the final phase of the experimental program full-height, masonry veneer curtain wall sections were subjected to a positive pressure loading (pressure applied on the brick wall). The purpose of this series of tests was to observe the load deflection behaviour of a typical section of veneer wall in conjunction with the performance of the tie support system. The effects of ties, tie arrangement and stud type on the deflection characteristics of this type of wall were investigated.

D.1 Specimen Description and Construction

A total of four wall sections were tested in this part of the experimental program.

Figures 15 and 16, on pages 35 and 36, show the construction details of a typical full size wall specimen. Two concrete slabs served as the frame for each of the specimens. The concrete slabs were separated by four 3.0 m long, round HSS columns. Attached to each slab was a 12 mm shelf angle used to support the brick veneer. These shelf angles were designed so that the maximum corbel of the brick veneer was 25 mm.

The construction of all the wall specimens followed the same sequence. The support track was fastened to the slabs using three expansion anchors on each track. Three steel studs were then attached to the track at a spacing of 400 mm on centre. The studs were held in position by number 14 self-tapping sheet metal screws, one at each

end. Two lines of 12 mm channel bridging were braced to the steel studs. This bridging was run through the two centre service cutouts. Gypsum board panels were then fastened to the studs by 38 mm, self drilling "Teck" screws spaced as shown in Figure 17, on page 37. The exterior insulating styrofoam panels were attached and held in position by the tie support device on which the tie was attached. All the mortar was mixed according to CSA A-178 specifications for Type S mortar. After the backing wall was completed, the butyl flashing and the brick ties were attached. The ties were fastened in the same manner as in the small tests. Then the brick veneer wall was built. Each wall was then cured for a minimum of 28 days. After twenty days of curing, the top expansion joint was filled with 12 mm, styrofoam backer rod and a sealant.

The brick veneer walls were built by a journeyman mason. A 5 mm raked mortar joint was provided. Special care was taken to ensure that the workmanship of the brickwork was comparable to a well-built wall in the field. The cavity was not cleaned.

D.2 Testing Apparatus and Procedures

The full sized wall sections were tested in the apparatus in Photo 7, on page 38. The testing frame consisted of four W-shape columns, four connecting beams, a backing wall comprised of a fluted steel deck and 12 mm plywood, and an air bag.

The wall specimens, shown in Photo 8, on page 39 were lifted into this frame by a crane. The specimens were transported using a cargo sling under the supporting angle and lifting hooks located at the rear of the bottom slab. By lifting in this way, the walls were not subjected to any stress due to transporting them. After the wall section was positioned in the apparatus, the top slab was bolted to the column by a connecting beam on each side. The bottom slab was brought to bear against a jack connected to the bottom of the columns.

A total of twelve variable differential transducers (LVDT) were used to measure the deflection of each wall section. Six monitored the deflection of the brick wall and six measured the deflection of the stud wall backing. The transducers were fastened to a common

frame, which in turn was fastened to the two rear supporting pipes.

The locations of the transducers on the brick veneer and on the stud backing wall are shown in Figure 18, on page 40. Wires connected the LVDT's to both the brick veneer and the backing wall. The wires were connected to the brick veneer using epoxy and extension rods. Screws were used to attach the wire to the stud backing wall. All the wires were tensioned using elastic bands.

The pressure in the air bag, and thus the load on the wall, was measured using a transducer attached to the air bag. Air was supplied from the laboratory 690 kPa air system using a series of pressure regulators.

All output from the measuring devices was monitored by a computerized data acquisition system.

After each wall specimen was fastened to the testing frame, a load of 0.30 kPa (6.3 psf) was applied to the wall to ensure proper seating of the specimen. The load was then removed and the gauges were set to zero. The wall was subsequently loaded by slowly increasing pressure in the air bag. The wall loading was continued until a peak load was reached.

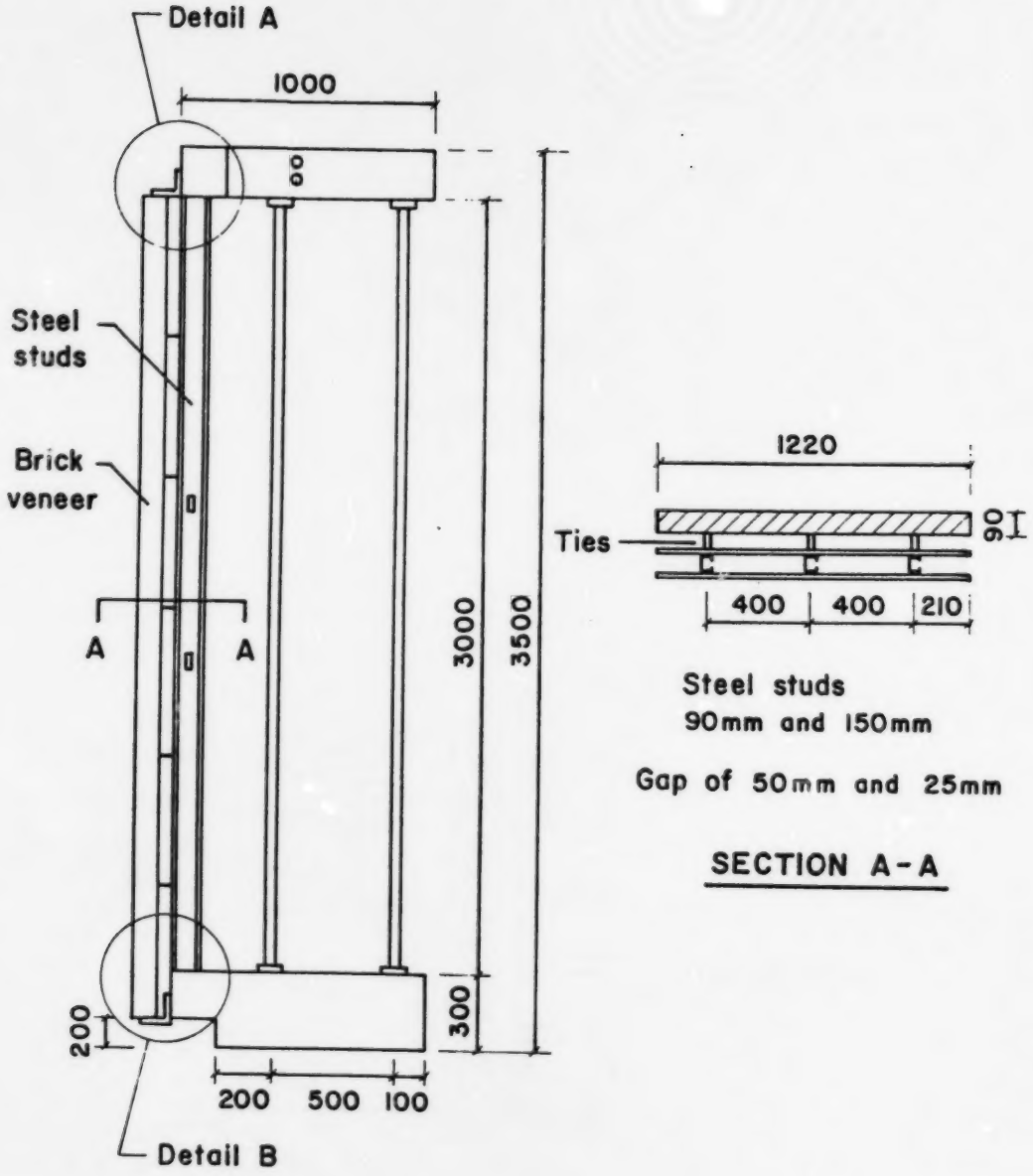
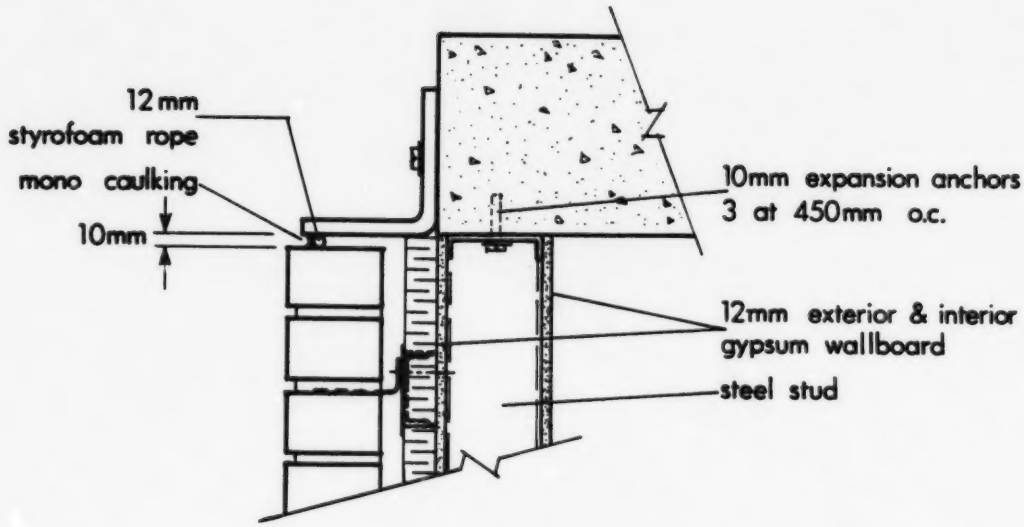
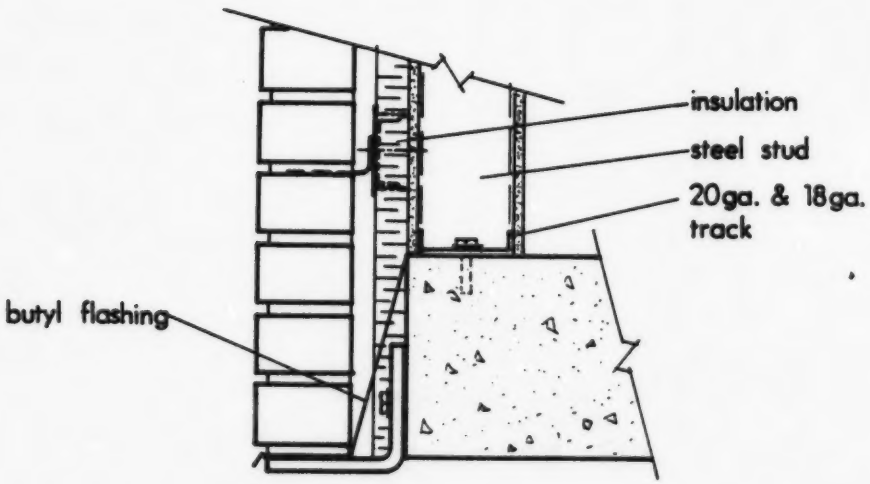


Figure 15. Full Sized Wall Specimen



DETAIL A



DETAIL B

Figure 16. Full Sized Wall Specimen Details

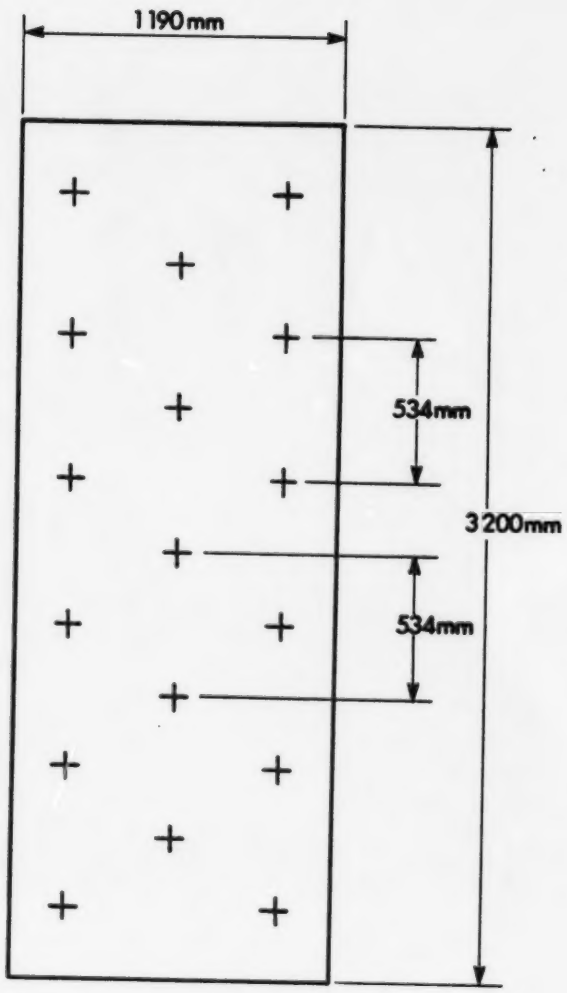


Figure 17. Tie Pattern for the Specimens

All the specimens are constructed using:
1 in. sytrofoam SM insulation
1 in. air space
400 mm spacing between metal studs
metal studs are all 3 5/8 in. deep and 3 m long.
All the specimens are 1.19 m x 3.20 m on the brick face.

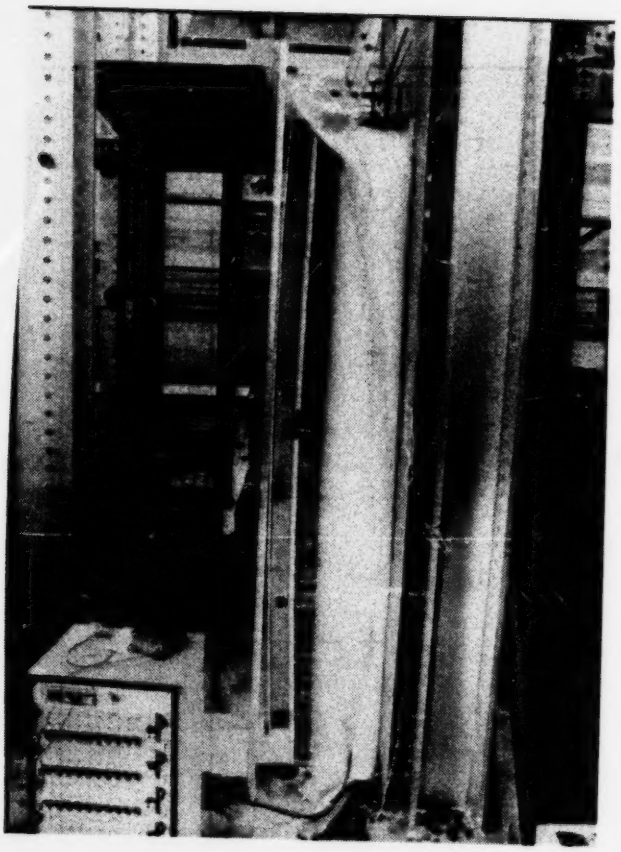


Photo 7. Full Sized Wall Test Frame

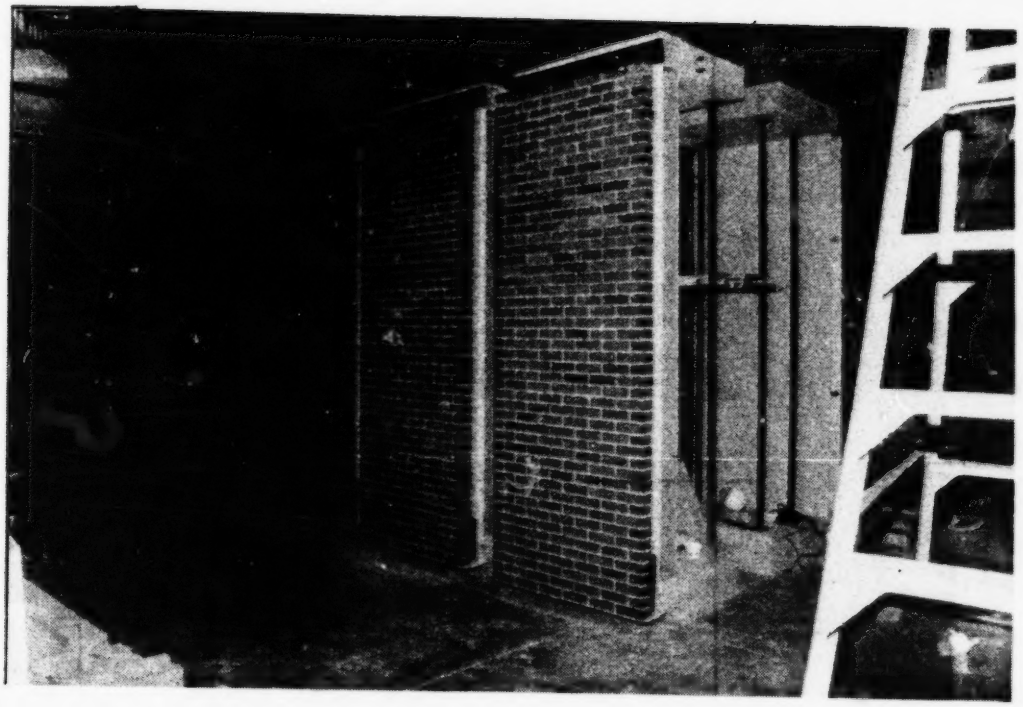


Photo 8. Full Scale Wall Specimen

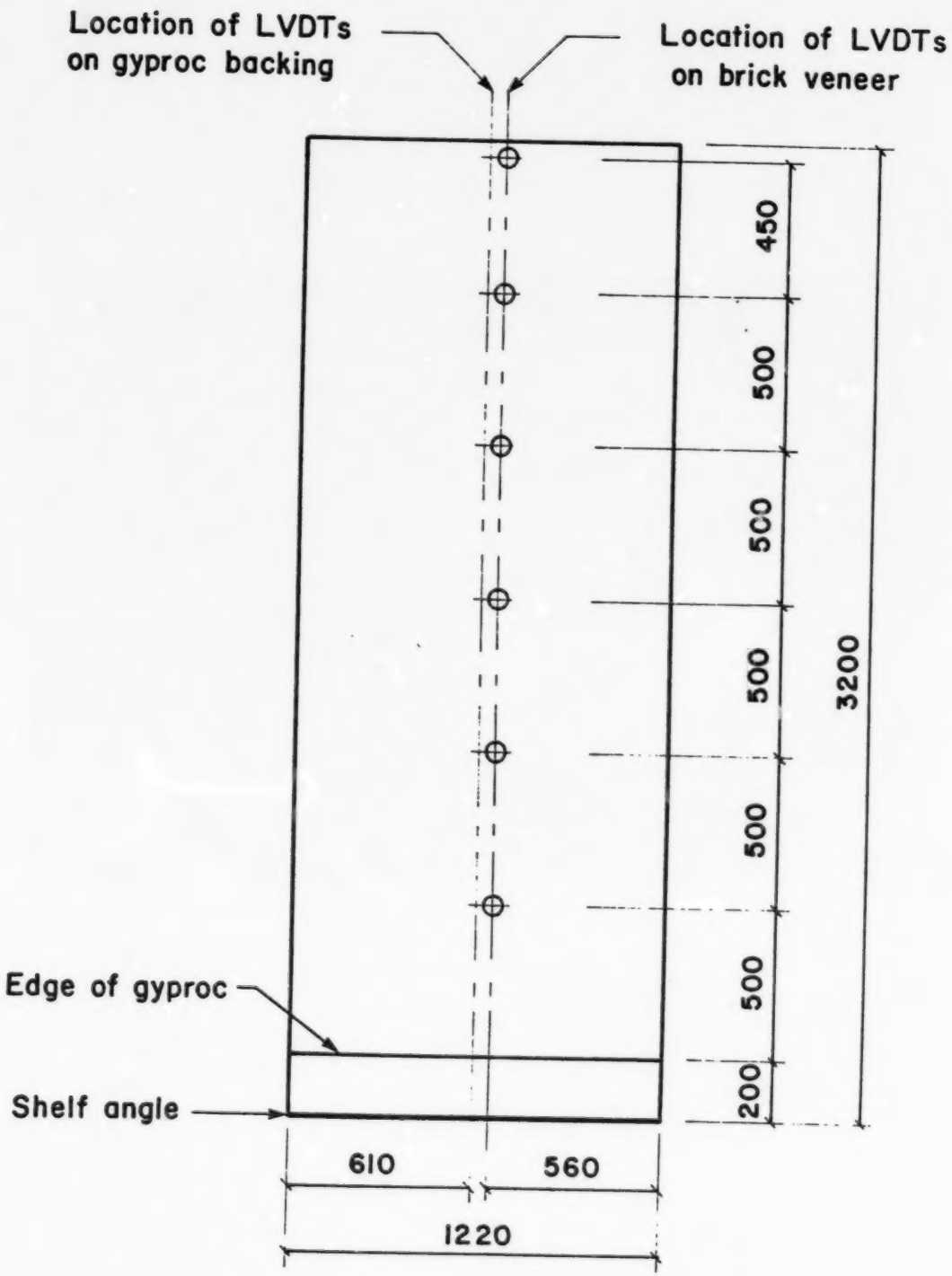


Figure 18. Location of the Measured Points of Deflection

Table 6. Test Results for the Wall Specimens

Specimen No.	Material Used	Maximum Pressure Applied (kPa)	Comments on Failure Modes
S1W1	22 G corrugated strip ties with tie support 18 G metal studs	4.16	Crack on the brick wall opened up between 25th to 26th course. Tie buckled. Test stopped when the top of the brick wall touched the insulation.
S1W2	22 G corrugated strip ties, no tie support 18 G metal studs	3.41	Crack on the brick wall opened up between 23rd and 24th course. Tie punched into the insulation causing local failure in the insulation. Test stopped when the brick wall touched the insulation.
S1W3	16 G corrugated strip ties with tie support 18 G metal studs	6.18	Crack on the brick wall opened up between 27th and 28th course. Final failure occurred when the metal studs buckled.
S1W4	16 G corrugated strip ties with tie support 16 G metal studs	7.07	Crack on the brick wall opened up between 25th and 26th course. No failure was observed on the ties, tie supports or the metal studs. Test stopped as the centreline deflection was too significant.

D.3 Full Scale Wall Test Results

The results obtained from the tests on full scale walls are summarized in Table 6, on page 41. On the same table construction details as they relate to ties, support devices and other pertinent information is provided. Failure modes are shown in Photos 9 through 14, on pages 43 through 46. Failure loads varied from 3.41 kPa to 7.07 kPa. Failures were caused by cracking of the brickwork, tie buckling or failure of the metal stud. No failure of support device was observed.

Load deflection curves for the walls tested are shown on Figures 19 through 22, on pages 47 through 50.

E. Discussion of Test Results

The results obtained from the testing of individual tie support devices indicate that the device can safely carry the loads expected when the assemblies are designed in accordance with S304 masonry design and construction for buildings.

When the tie support is attached to the back-up wall with insulation present, there is an increase in the ultimate load. This increase is attributed to the fact that the load is applied over a larger area and because some restraint is provided by the insulation. It should also be noted here that if the spacing of the masonry ties is increased and larger capacity is required the thickness of the material used in manufacturing the tie support device can be increased. The results obtained from the full scale wall testing indicate that the device developed can provide for support of the loads expected on a brick veneer wall designed in accordance with existing code requirements.

Photo 9. Tie Failure - Wall S1W1

Photo 10. Tie Failure - Wall S1W2

Photo 11. Crack Formation During Testing

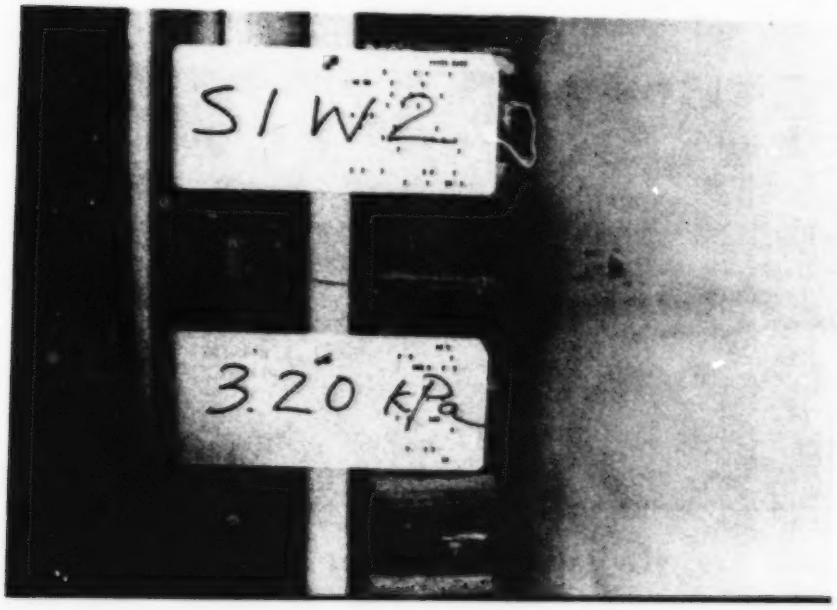


Photo 12. Cracking of Wall S1W2

Photo 13. Stud Failure - Wall S1W3

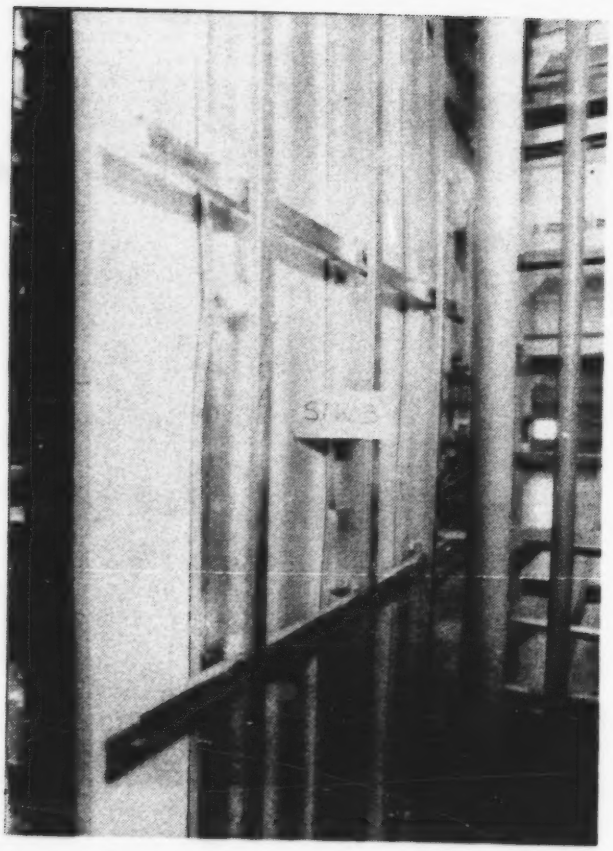


Photo 14. Failure of Back-up System - Wall S1W3

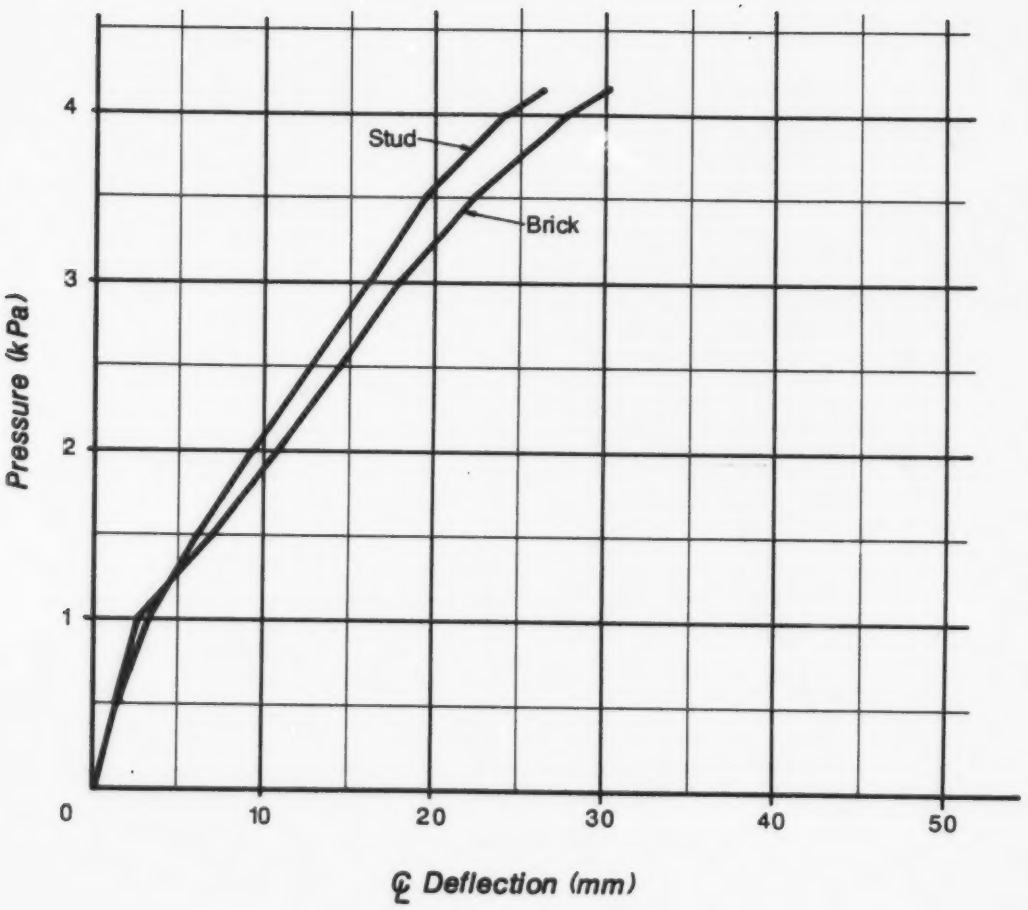


Figure 19. Load (kPa) vs Centerline Deflection (mm) for S1W1

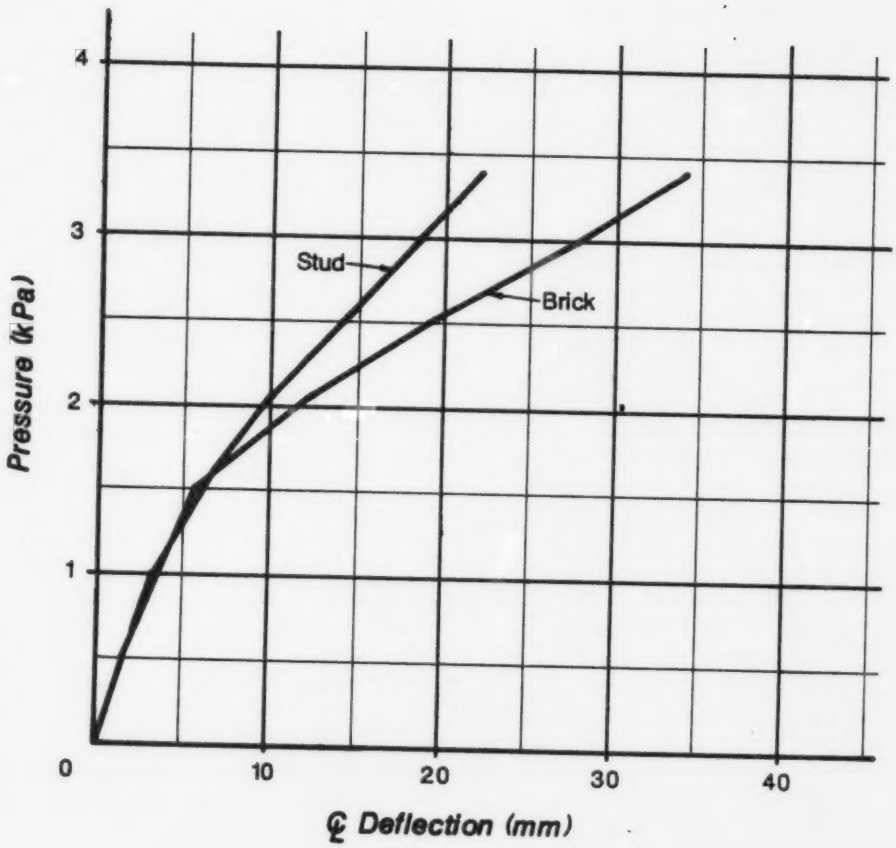


Figure 20. Load (kPa) vs. Centerline Deflection (mm) for S1W2

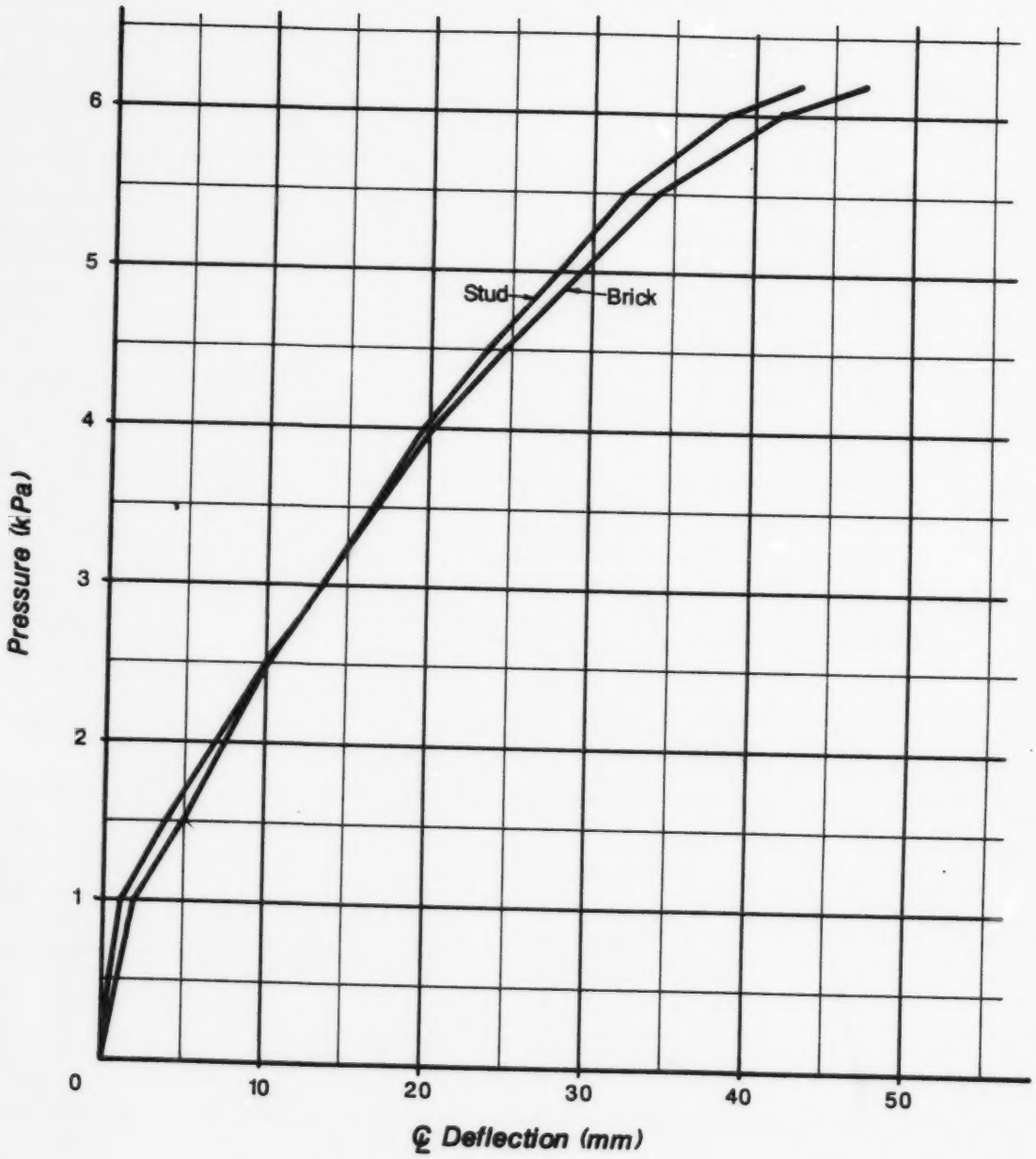


Figure 21. Load (kPa) vs. Centerline Deflection (mm) for S1W3

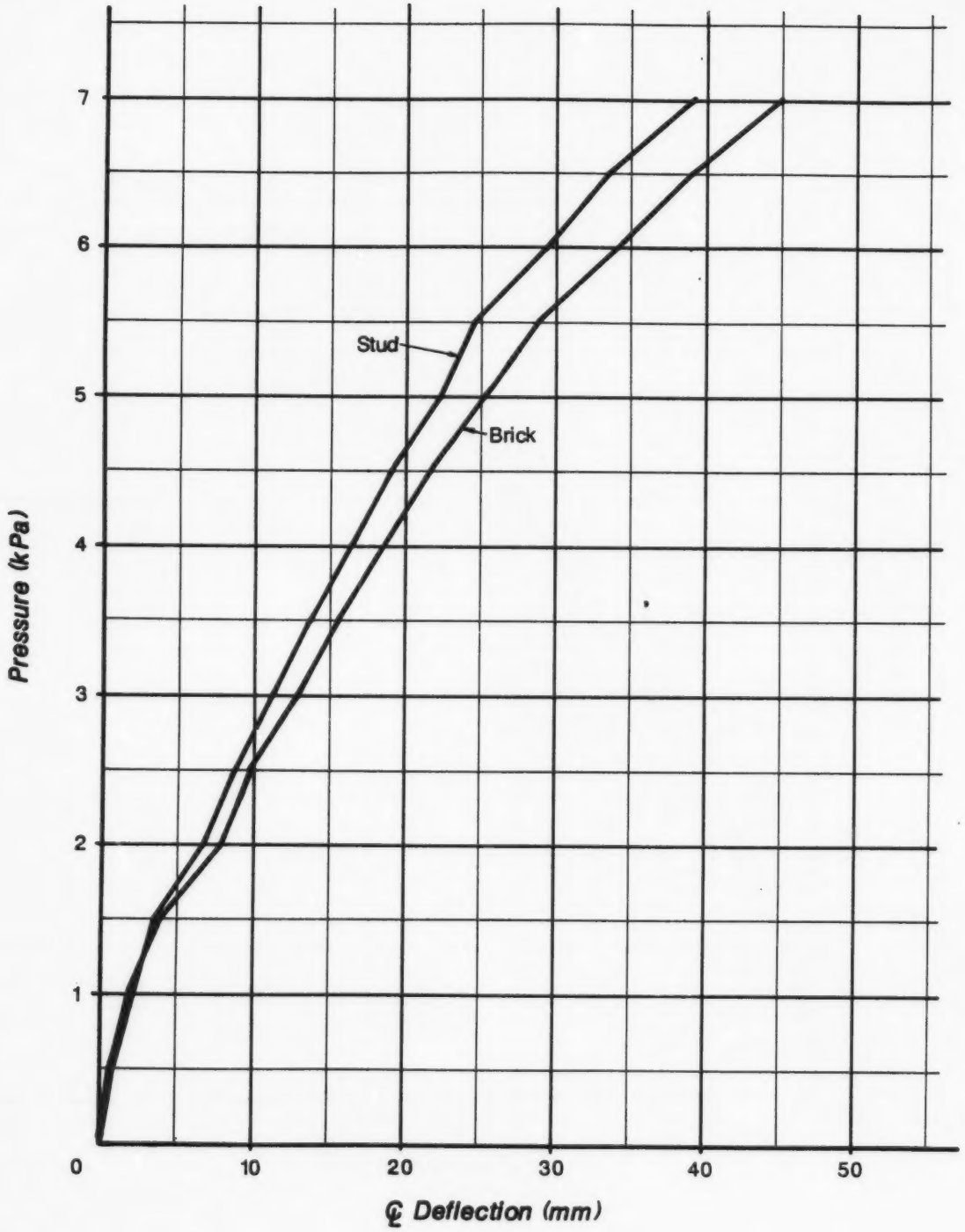


Figure 22. Load (kPa) vs. Centerline Deflection (mm) for S1W4

CHAPTER VI. Summary and Conclusions

A. The tie support device developed in this study can provide adequate support for the masonry ties used to transfer loads from the brick veneer to the back-up metal stud or wood stud wall.

B. When the device is used, the assembly strength is governed by the capacity of the components.

C. For design purposes the unsupported length of the masonry tie is reduced by the height of the tie support device. (Placement of insulation which increases greatly the capacity of the tie support device.)

D. The strength of the device can be increased if needed by using thicker material.

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APPENDIX

COMPUTER FRAME ANALYSIS RESULTS

Analysis of 25 mm Device

```
r cive:pft 5=pft.11
#09:30:06


***Input/output units:  SI by default


***Problem control variables:

   Type of structure                = Frame
   Number of joints                 =  14
   Number of elements               =  13
   Number of load cases             =   1
   Number of bdy. joints            =   2


***Nodal geometry as input (metres)

  Node    X-coordinate             Y-coordinate

    1     0.0                      0.0
    2     0.200000E-02             0.400000D-02
    3     0.400000E-02             0.800000E-02
    4     0.600000E-02             0.120000E-01
    5     0.800000E-02             0.160000E-01
    6     0.100000E-01             0.200000E-01
    7     0.118125E-01             0.236250E-01
    8     0.681875E-01             0.236250E-01
    9     0.700000E-01             0.200000E-01
   10     0.720000E-01             0.160000E-01
   11     0.740000E-01             0.120000E-01
   12     0.760000E-01             0.800000E-02
   13     0.780000E-01             0.400000E-02
   14     0.800000E-01             0.0


***Member property default values:

   Area                             = 1.00000 sq. mm.
   Moment of inertia                = 1.00000 (mm)**4
   Young's Modulus                  = 200000. MPa
   Coeff. of Thermal Exp.           = 0.100000E-03
```

***Member data as input:

Member	I-node	J-node	Type	Area	Inertia
1	1	2	0	6.00000	8.00000
2	2	3	0	18.0000	72.0000
3	3	4	0	30.0000	280.000
4	4	5	0	42.0000	728.000
5	5	6	0	54.0000	1512.00
6	6	7	0	65.4375	2648.26
7	7	8	0	42.0000	65.8440
8	8	9	0	65.4375	2648.26
9	9	10	0	54.0000	1512.00
10	10	11	0	42.0000	728.000
11	11	12	0	30.0000	280.000
12	12	13	0	18.0000	72.0000
13	13	14	0	6.00000	8.00000

***External boundary conditions:

Joint	Rx	Ry	Rr
1	1	1	0
14	1	1	0

Load case no. 1
****

***Member loads as input:

Member	Type	u-projection	v-projection	Start-load
7	1	0.0	-1.00000	1.00000

***Nodal displacements (mm & radians)

Node	X	Y	R
1	0.0	0.0	0.1827E-02
2	-0.01	0.00	0.2435E-03
3	-0.01	-0.00	-0.2845E-03
4	-0.01	-0.00	-0.5107E-03
5	-0.00	-0.00	-0.6326E-03
6	-0.00	-0.00	-0.7080E-03
7	0.00	-0.01	-0.7553E-03
8	-0.00	-0.01	0.7553E-03
9	0.00	-0.00	0.7080E-03
10	0.00	-0.00	0.6326E-03

***Nodal displacements (con't)

Node	X	Y	R
11	0.01	-0.00	0.5107E-03
12	0.01	-0.00	0.2845E-03
13	0.01	0.00	-0.2435E-03
14	0.0	0.0	-0.1827E-02

***Member end forces (KN : KN m)

Member	I	J	Ni	Vi	Mi	Nj	Vj	Mj
1	1	2	0.686	-0.253	0.0	-0.686	0.253	-0.001
2	2	3	0.686	-0.253	0.001	-0.686	0.253	-0.002
3	3	4	0.686	-0.253	0.002	-0.686	0.253	-0.003
4	4	5	0.686	-0.253	0.003	-0.686	0.253	-0.005
5	5	6	0.686	-0.253	0.005	-0.686	0.253	-0.006
6	6	7	0.686	-0.253	0.006	-0.686	0.253	-0.007
7	7	8	0.533	0.500	0.007	-0.533	0.500	-0.007
8	8	9	0.686	0.253	0.007	-0.686	-0.253	-0.006
9	9	10	0.686	0.253	0.006	-0.686	-0.253	-0.005
10	10	11	0.686	0.253	0.005	-0.686	-0.253	-0.003
11	11	12	0.686	0.253	0.003	-0.686	-0.253	-0.002
12	12	13	0.686	0.253	0.002	-0.686	-0.253	-0.001
13	13	14	0.686	0.253	0.001	-0.686	-0.253	0.0

Analysis of 75 mm Device

```
r cive:pft 5=pft.22
#10:50:35

***Input/output units:  SI by default

***Problem control variables:

   Type of structure              = Frame
   Number of joints               =  14
   Number of elements             =  13
   Number of load cases           =   1
   Number of bdy. joints          =   2

***Nodal geometry as input (metres)

  Node   X-coordinate          Y-coordinate

    1    0.0                   0.0
    2    0.171400E-02          0.120000E-01
    3    0.342900E-02          0.240000E-01
    4    0.514300E-02          0.360000E-01
    5    0.685700E-02          0.480000E-01
    6    0.857100E-02          0.600000E-01
    7    0.105180E-01          0.736250E-01
    8    0.694820E-01          0.736250E-01
    9    0.714290E-01          0.600000E-01
   10    0.731430E-01          0.480000E-01
   11    0.748570E-01          0.360000E-01
   12    0.765710E-01          0.240000E-01
   13    0.782860E-01          0.120000E-01
   14    0.800000E-01          0.0

***Member property default values:

   Area                       = 1.00000 sq. mm.
   Moment of inertia          = 1.00000 (mm) **4
   Young's Modulus            = 200000. MPa
   Coeff. of Thermal Exp.     = 0.100000E-03
```

***Member data as input:

Member	I-node	J-node	Type	Area	Inertia
1	1	2	0	5.14400	5.04000
2	2	3	0	15.4290	45.3410
3	3	4	0	25.7150	176.336
4	4	5	0	36.0000	458.441
5	5	6	0	46.2860	952.159
6	6	7	0	57.2690	1793.34
7	7	8	0	42.0000	65.8440
8	8	9	0	57.2690	1793.34
9	9	10	0	46.2860	952.159
10	10	11	0	36.0000	458.441
11	11	12	0	25.7150	176.336
12	12	13	0	15.4290	45.3410
13	13	14	0	5.14400	5.04000

***External boundary condition:

Joint	Rx	Ry	Rr
1	1	1	0
14	1	1	0

Load case no. 1
****

***Member loads as input:

Member	Type	u-projection	v-projection	Start-load
7	1	0.0	-1.00000	1.00000

Young's Modulus	Tcoeff.	(length)
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121219E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.137634E-01
200000.	0.100000E-03	0.589640E-01
200000.	0.100000E-03	0.137634E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121218E-01
200000.	0.100000E-03	0.121219E-01
200000.	0.100000E-03	0.121218E-01

***Nodal desplacements (mm & radians)

Node	X	Y	R
1	0.0	0.0	0.7887E-02
2	-0.07	0.0	0.1666E-02
3	-0.08	0.0	-0.4080E-03
4	-0.07	0.00	-0.1297E-02
5	-0.05	-0.00	-0.1775E-02
6	-0.03	-0.01	-0.2072E-02
7	0.00	-0.01	-0.2293E-02
8	-0.00	-0.01	0.2293E-02
9	0.03	-0.01	0.2072E-02
10	0.05	-0.00	0.1775E-02
11	0.07	0.00	0.1297E-02
12	0.08	0.00	0.4080E-03
13	0.07	0.00	-0.1666E-02
14	0.0	0.0	-0.7887E-02

***Member end forces (KN & KN m)

Member	I	J	Ni	Vi	Mi	Nj	Vj	Mj
1	1	2	0.517	-0.085	0.0	-0.517	0.085	-0.001
2	2	3	0.517	-0.085	0.001	-0.517	0.085	-0.002
3	3	4	0.517	-0.085	0.002	-0.517	0.085	-0.003
4	4	5	0.517	-0.085	0.003	-0.517	0.085	-0.004
5	5	6	0.517	-0.085	0.004	-0.517	0.085	-0.005
6	6	7	0.517	-0.085	0.005	-0.517	0.085	-0.006
7	7	8	0.158	0.500	0.006	-0.158	0.500	-0.006
8	8	9	0.517	0.085	0.006	-0.517	-0.085	-0.005
9	9	10	0.517	0.085	0.005	-0.517	-0.085	-0.004
10	10	11	0.517	0.085	0.004	-0.517	-0.085	-0.003
11	11	12	0.517	0.085	0.003	-0.517	-0.085	-0.002
12	12	13	0.517	0.085	0.002	-0.517	-0.-85	-0.001
13	13	14	0.517	0.085	0.001	-0.517	-0.085	0.0

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0.113 CPu SEC.
124.716 ELAPSED SEC.
10:52:40 T=0.169 RC=0